

Chemical Abundances in the Carina dSph Galaxy

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Abstract. We report on the chemical abundances of stars in the Carina dwarf spheroidal galaxy (dSph) derived from low-resolution spectra. We have determined values of $[\text{Fe}/\text{H}]$ for 52 stars from the reduced equivalent width of the Ca II infrared triplet lines. The Carina dSph has a mean metallicity of $[\text{Fe}/\text{H}] = -1.99 \pm 0.08$ and an intrinsic metallicity dispersion 0.25 dex (1σ). By directly determining the chemical abundances of Carina stars through spectroscopy, we can overcome the age-metallicity degeneracy inherent in color-magnitude diagrams (CMDs) and determine its star-formation history with unprecedented accuracy.

1. Introduction

The dSphs in the Local Group offer a unique opportunity for testing our understanding of galaxy evolution. New CMDs obtained for dSphs show that most have undergone complex evolution. They formed stars over *many Gyr* rather than on a dynamical timescale (few $\times 10^8$ yr) despite the fact that they are now devoid of gas and their low total masses (10^7 to $10^9 M_\odot$) make them highly susceptible to supernova-driven galactic winds. (For a recent review, see Smecker-Hane 1997.) We have undertaken a series of studies involving photometry and spectroscopy of stars in the Carina and Fornax dSphs to determine their star-formation and chemical evolution histories. Here we report on our spectroscopy of Carina dSphs stars and their derived metallicities.

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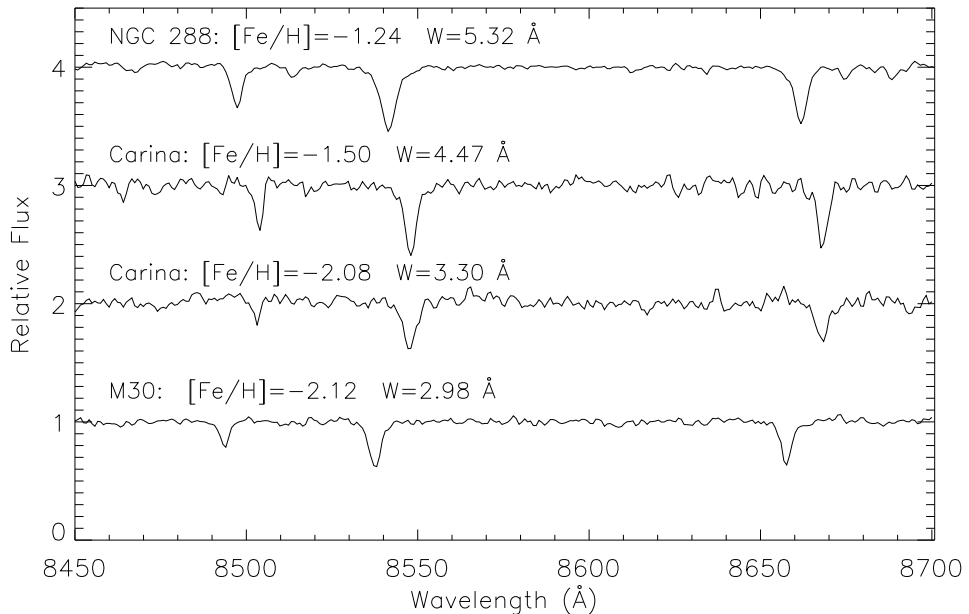


Figure 1. Spectra of Carina dSph and globular cluster stars. The Ca II lines at 8542 and 8662 Å are used to derive metallicities.

2. Observations and Data Analysis

We used our photometric survey of bright stars centered on the Carina dSph (Smecker-Hane, et al. 1994) to identify red giants that were probable members of the galaxy. At a Galactic latitude of $b = -22^\circ$, the Carina fields are contaminated with a significant number of Galactic foreground stars. Although members cannot be positively identified by their location in the CMD, they are easily identified by their large radial velocities (223 km/sec). For our spectroscopic sample, we randomly chose stars from the CMD that had magnitudes within 1.5 mag of the tip of the red giant branch (RGB), (B-I) colors within ± 0.14 of the mean color of the RGB, and distances < 11 arcmin (1 core radius) from the center of the galaxy.

We obtained spectra of these stars with the Cerro Tololo Inter-American Observatory 4.0-meter telescope and the ARGUS multi-fiber system in November, 1997. The ARGUS system allows simultaneous observation of 24 stars and 24 sky positions. Total exposure times were 3.5 to 5 hours. Images were reduced using the standard CCD reduction package in the Image Reduction and Analysis Facility (IRAF), and the spectra were extracted and calibrated with the ARGUS package. The most difficult part of the data reduction was the sky subtraction because the Ca II lines fall among bright night sky emission lines. The fluxes in the sky lines were typically 5 times higher than the stellar continuum fluxes in the region of the Ca II lines. The final stellar spectra have a dispersion of 0.83 Å/pix , and a typical signal-to-noise ratio of 17 per pixel. Examples are shown in Figure 1.

3. Chemical Abundances

We derived metallicities, $[\text{Fe}/\text{H}]$, from the reduced equivalent width, W' , of the Ca II infrared triplet lines in each spectrum. This technique has been empirically calibrated by Rutledge, et al. (1997) using observations of numerous Galactic globular cluster stars, and interested readers are referred to it for details. In brief, the sum of the equivalent widths of the two strongest lines of the Ca II triplet at 8542 and 8662 Å, W , shows a linear dependence with $[\text{Fe}/\text{H}]$ when the effect of effective temperature and gravity are removed to first order. The later is effectively done by forming the reduced equivalent width for each star, $W' \equiv W + 0.62(V - V_{HB})$, where V is the magnitude of the star and V_{HB} is the magnitude of the horizontal branch. The equivalent width for each Ca II line was determined by fitting a linear continuum plus Gaussian-shaped absorption feature in the standard wavelength regions defined by Armandroff & Da Costa (1991). The adopted calibration equation, $[\text{Fe}/\text{H}] = -2.66 + 0.42W'$, from Rutledge, et al. (1997) gives metallicities based on the scale defined by the high-dispersion spectroscopic work of Carretta & Gratton (1997).

Figure 2 shows a histogram of the derived metallicities for 52 radial velocity members of Carina and a Gaussian fit to the histogram. The average metallicity is $[\text{Fe}/\text{H}] = -1.99 \pm 0.08$ (including the calibration zeropoint error in the uncertainty) and the observed dispersion is $\sigma = 0.30 \pm 0.02$ dex. The error in each derived metallicity is set primarily by the sky flux and random fiber-star positioning errors. Thus the $[\text{Fe}/\text{H}]$ measurement errors are, to first order, independent of the magnitude and metallicity of the stars in the limited magnitude range over which we are observing. Subtracting in quadrature the average measurement error of 0.15 dex and 0.02 dex uncertainty in the slope of the calibration from the observed dispersion reveals an intrinsic metallicity dispersion of $\sigma = 0.25$ dex (1.0 dex full width) for the Carina dSph.

Two notable calibration issues deserve discussion. First, the W' - $[\text{Fe}/\text{H}]$ calibration is strictly valid for old stars although Armandroff & Da Costa (1991) note no strong age dependence. Second, the calibrating Galactic globular clusters exhibit a relatively well-defined relationship in $[\text{Ca}/\text{Fe}]$ versus $[\text{Fe}/\text{H}]$ that reflects the history of enrichment from Type Ia and Type II supernovae in the Galaxy. However dwarf galaxies may have entirely different star-formation histories and may not share the same $[\text{Ca}/\text{Fe}]$ - $[\text{Fe}/\text{H}]$ relationship (see Smecker-Hane & McWilliam in these proceedings for a discussion of abundance ratios in the Sagittarius dSph). Therefore, we are embarking on a series of observations to calibrate W' to yield $[\text{Ca}/\text{H}]$ and to explore its sensitivity to age.

4. Discussion

The derived mean metallicity and intrinsic metallicity dispersion roughly agree with our initial analysis of the Carina CMD (Smecker-Hane 1997) although the metallicity dispersion derived from spectroscopy is larger. A full analysis of the CMD is underway to determine Carina's star-formation history. Carina's RGB is very narrow in color because of the degeneracy of age and metallicity. A wide range in age (~ 2 to 14 Gyr) counteracts a 1.0 dex spread in metallicity in such a way that the younger RGB stars are more metal rich and hence have

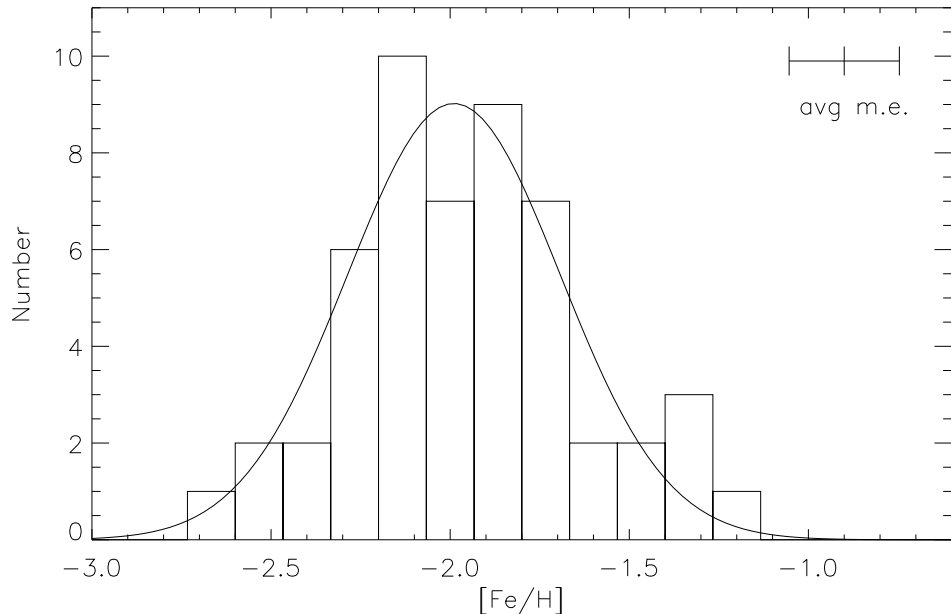


Figure 2. The metallicity histogram for 52 members of the Carina dSph galaxy. The average $1\text{-}\sigma$ measurement error of 0.15 dex is shown in the upper right-hand corner.

approximately the same colors as the older, more metal-poor, RGB stars. Thus a galaxy with a narrow RGB may indeed have a complex stellar population. An interesting contrast to the Carina dSph is the Leo I dSph. From analysis of its CMD, Gallart, et al. (1999) conclude that its wide RGB may be a result of its wide range in age (~ 1 to $10 - 15$ Gyr) and its internal metallicity dispersion may be very small. In conclusion, the dSphs exhibit a very wide variety of star-formation and chemical evolution histories, and we can learn much about the physical mechanisms that control their evolution by studying them in detail.

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